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REPORT

TO

ALBERTA ENVIRONMENT

ON

HYDROGEOLOGICAL EVALUATION

OF THE

LITTLE BOW RIVER SITE 7B-1

OUR FILE: A85-2106

NOVEMBER, 1985

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1. INTRODUCTION

1.1 TERMS OF REFERENCE

Alberta Environment (Planning Division) is reviewing the feasibility of an earthfill dam in the Little Bow River valley. The purpose of this dam would be to provide water storage for agricultural purposes. The resulting reservoir would have a maximum depth of 19 m at the dam and would extend north approximately 11.5 km. The reservoir would also extend approximately 3.5 km west along the Mosquito Creek valley.

Piteau Engineering Ltd. has been retained to provide a preliminary assessment of the hydrogeological setting of the reservoir. In particular, the study, as outlined in the Terms of Reference dated September 23, 1985, is to include:

1. a review of geological, hydrogeological and geotechnical literature;

2. a field reconnaissance of accessible bedrock outcrops within the reservoir area;

3. hand augered holes in areas without bedrock outcrops; and

4. hydraulic conductivity tests in a limited number of the hand augered holes.

This report describes the work and testing performed by Piteau Engineering Ltd. The field program was conducted in two stages: a preliminary

reconnaissance on September 29, 1985 and field mapping and testing on October 3-4, 1985. The literature review included Alberta Environment well records, PFRA and other technical reports, and Alberta Research Council maps on the Little Bow River area. An hydrogeological air photo assessment of the reservoir was also performed.

1.2 LOCATION, CLIMATE AND TOPOGRAPHY

The proposed location of the Little Bow River 7B-1 dam is approximately 2 km downstream of the junction of the Little Bow River and Mosquito Creek, in N.W. SEC 5, TWP 15, RGE 25, W4M. The reservoir would extend north into NE SEC 8, TWP 16, RGE 26, W4M, and west into SE SEC 11, TWP 15, RGE 26, W4M. The damsite is situated about 18 km due east of the hamlet of Parkland (Figure 1).

The mean January, July and annual temperatures at Gleichen, to the north, are -12.2°C, 17.9°C and 3.5°C, respectively. The mean January, July and annual temperatures at Vauxhall, to the east, are -10.7°C, 18.9°C and 4.3°C, respectively (Canada Department of Transport, Meteorological Branch, 1967). The mean annual precipitation is 419 mm and the annual potential evapotranspiration is approximately 762 mm near Nanton (Ozoray and Lytviak, 1974). Hence, the potential evapotranspiration exceeds the precipitation in the area.

The proposed dam and reservoir lie near the western edge of the Interior Plains physiographic region. Local relief is hummocky and relatively subdued, with the exception of the Little Bow River and Mosquito Creek valleys, and various glacial deposits such as kames and eskers. The valleys are steep-sided, flat-bottomed and incised approximately 25 m below the uplands.

Both the Little Bow River and Mosquito Creek belong to the Oldman River drainage basin. Surface drainage in the area of interest is generally towards these water courses. Localized run-off may also be into closed depressions, where the water either infiltrates into the ground or evaporates.

2. GEOLOGIC SETTING

2.1 BEDROCK GEOLOGY

Bedrock in the reservoir area consists primarily of the Lower Tertiary/ Upper Cretaceous Willow Creek Formation. This unit consists of interbedded grey calcareous sandstone and bentonitic mudstone (shale) with occasional thin beds of limestone. The remaining thickness of the Willow Creek Formation varies from greater than 300 m to the west of the reservoir, to 0 m a few kilometres to the east. Underneath the reservoir, the thickness is approximately 200 m (Ozoray and Lytviak, 1974).

The bedrock surface in the reservoir area is shallow, usually less than 20 m below the ground surface on the uplands, 5 - 10 m in the valleys and is relatively flat. Bedrock is intermittently exposed on the slopes of both the Little Bow River and Mosquito Creek valleys.

2.2 SURFICIAL DEPOSITS

Surficial deposits of pre-glacial (and/or inter-glacial), glacial, and post-glacial origin are present in the reservoir study area (Figure 2).

In pre-glacial times, a drainage system of river valleys was developed in southern Alberta. The valleys were incised into bedrock and later filled with sands and gravels. According to Geiger (1968), the pre-glacial Tee Pee Valley follows the same course as the present day Little Bow River. This valley was part of the Lethbridge valley system. The remaining thickness of the sands and gravels in the Tee Pee Valley is approximately 1 m near the dam and undetermined elsewhere along the

reservoir. Thurber Consultants Ltd. (1985) notes that "the northern part of the Travers Reservoir is located over such a buried valley (Tee Pee Valley), apparently without serious problems to date".

Glacial till, water modified at the surface, is the most extensive surficial deposit on the uplands and forms a moraine plain. It overlies the bedrock on the east side of the reservoir and is underlain by interglacial (or preglacial) alluvium to the west (PFRA, 1971). The alluvium overlies the bedrock on the west side. The till is typically a heterogeneous deposit consisting of clay with layers of sand and silt and occasional boulders. The alluvial deposit consists primarily of clays and interbedded clayey sands and is 6 m thick (PFRA, 1971).

Glaciolacustrine deposits form a thin veneer of fine-grained sand over the till to the east and adjacent to the reservoir. Glaciofluvial deposits, such as kames and eskers, are locally abundant to the west of the Little Bow River valley. In particular, the shape of Clear Lake is controlled by parallel eskers.

In the Little Bow River valley, deposits consist primarily of post-glacial alluvium and colluvium which overlie bedrock and pre-glacial deposits. The alluvium has formed floodplains and terraces and is comprised of fine-grained sands, silts, and clays. In places along the Little Bow River valley, glaciofluvial deposits were deposited and were not removed by post-glacial erosion. These localized deposits consist of gravelly sand to clay-sized material and generally form a higher level terrace than the post-glacial alluvium. The colluvium is derived from glacial and alluvial material adjacent to the valley slopes, and has formed slopewash deposits along the walls and floors of meltwater channels.

3. HYDROGEOLOGIC SETTING

3.1 HYDROGEOLOGY

The regional groundwater flow in the Little Bow area is eastward, from recharge zones in the Rockies and the Foothills to the Interior Plains region. This flow is relatively deep. On a local scale, the Little Bow River and Mosquito Creek valleys act as a drainage area intercepting shallow groundwater flow and surface water.

The term hydrostratigraphic unit describes water-bearing zones of similar groundwater recharge, circulation and hydrochemical conditions. A lower (bedrock) hydrostratigraphic unit is represented by the Willow Creek Formation. Previous drilling in this unit with minimal circulation losses suggests that it is relatively tight (PFRA, 1971). An Alberta Research Council test well was completed in bedrock in the Little Bow River valley at LSD 16, SEC 12, TWP 15, RGE 26, W4M (Figure 3). This well was bail tested for two hours at a depth of 40.5 m and at a rate of 0.76 l/s (Appendix I). Based on this test, the 20-year safe yield was determined to be approximately 0.41 l/s.

The various surficial deposits of glacial and/or alluvial origin form an upper hydrostratigraphic unit. This unit contains lenses and/or layers of higher hydraulic conductivity sand and/or silt. Within the glacial till, which surrounds the majority of the reservoir on the uplands, the lenses are likely discontinuous. However, the interglacial alluvium on the west side contains clayey sand layers which may be continuous. Ozoray and Lytviak (1984) have estimated the 20-year safe yields of this unit to be no greater than 1.67 l/s. Neither the upper nor the lower hydrostratigraphic unit is considered a regional groundwater source.

A third hydrostratigraphic unit may be represented by the buried preglacial sands and gravels in the Tee Pee Valley. The exact nature and extent of this deposit is unknown, but safe yields in similar preglacial deposits are as high as 7.5 l/s (Ozoray and Lytviak, 1974).

A second bail test was performed by the Alberta Research Council (in the test well at LSD 16, SEC 12, TWP 15, RGE 26, W4M) at a depth of 10.7 m in gravels above the bedrock. This test induced infiltration from the Little Bow River (Ozoray and Lytviak, 1974), indicating a hydraulic connection with the river above bedrock. These gravels are possibly part of the pre-glacial Tee Pee Valley.

3.2 HYDROCHEMISTRY

Groundwater in the region is generally a soft sodium-bicarbonate-sulphate type. This type represents a mature water where sodium has replaced calcium in a cation exchange process. The total dissolved solids (TDS) of this water commonly ranges between 500 and 1000 mg/l, which is typical of southern Alberta. Local TDS anomalies with values approaching 4000 mg/l are sporadically present around the area (Appendix I). The chloride content of the groundwater, in milliequivalents, is usually less than 10% of the total anion content.

Water impounded in the reservoir would be of better chemical quality than the local groundwater. Therefore, the introduction of this water would probably be beneficial to shallow groundwater in the area. Groundwater chemistry would also be affected by the cyclic aeration and saturation of soil or upper bedrock due to the lowering and raising of the reservoir level. Such fluctuations may increase metal concentrations in groundwater. However, these fluctuations would be limited to areas adjacent to the reservoir. Also, as most domestic wells are completed deeper in bedrock, any adverse affects would likely be minimal.

4. FIELD EXPLORATION PROGRAM

4.1 OBJECTIVES

The primary objectives of the field exploration program were to:

1. assess the distribution and hydrogeologic nature of soil and bedrock outcrops in the reservoir;

2. sample and classify surface deposits; and

3. determine the hydraulic conductivities of the surface deposits.

This information, coupled with available literature, could then be used to provide a preliminary qualitative assessment of the proposed reservoir.

4.2 HYDROGEOLOGIC MAPPING

Hydrogeologic mapping was performed along the entire length of the reservoir. Outcrops were usually located on the sides of valleys where colluvium had been eroded, or in gulleys that had been incised downwards. Bedrock consisted of light-grey, fine-medium grained calcareous sandstone with interbeds of medium-grey bentonitic shale or mudstone, of the Willow Creek Formation. The calcareous sandstone was harder and much less susceptible to weathering. Bedding was typically near horizontal. Frequently, the bedrock was covered by less than 2-3 m of colluvium on the valley sides.

Surficial deposits were either of glacial and/or alluvial origin. On the uplands, the ground surface consisted of a silt and/or sand and was strewn with sub-rounded boulders. In the valleys, the surface deposits were primarily stratified post-glacial alluvium consisting of clayey silt and sand. These were visible along the banks of the water courses and steep valley slopes. On the north side of the Mosquito Creek, about 2 km upstream of the junction with the Little Bow River, interglacial (or pre-glacial) alluvium approximately 6 m thick underlays the surface glacial drift. This may be the same deposit identified in PFRA (1971) on the west side of the Little Bow River, near the proposed dam site. The alluvium consisted of interbedded silty clay and fine sand. Colluvium on the valley slopes was derived from either the glacial or alluvial material.

A few shallow slumps were located along the reservoir sides and were often associated with groundwater seepage. No major springs were identified and any discharge zones were limited to the lower part of valley slopes. In general, the groundwater surface elevation in the valleys was at or near the ground surface. On the uplands, surface water was rarely observed except for local ponding in shallow depressions. Flooding does not appear to be a concern due to the high ground surface elevations of areas bordering the reservoir.

4.3 HAND AUGERED HOLES AND HYDRAULIC CONDUCTIVITY TESTS

Hand auger holes were drilled at the proposed dam location and along the reservoir (Figure 4). The depth of these holes was approximately 1 m and the diameter was 13.3 cm. The holes were augered in alluvium in the valley bottom or glacial material on the uplands and were all above the groundwater surface. The borehole logs are presented in Appendix II.

The lithology at each location was identified and then a hydraulic conductivity test was performed (Table 1). The samples of the test locations were a silt and/or sand, with a variable clay content. Since each hole was uncased, it could be approximated by an open well. An empirical formula used to calculate hydraulic conductivities for this case is described by Pazdro (1977). The formula is shown with Figure 5 and describes a constant head test. Each hole was backfilled upon completion of testing.

The hydraulic conductivities (K) for all the holes tested ranged from 2×10^{-5} to 5×10^{-6} m/s, less than an order of magnitude difference. This magnitude of K is moderate to high and is typical of silty sand. However, these tests were performed in shallow holes and are therefore representative of only near surface material.

Hydraulic conductivities were also determined using grain size distributions from PFRA, 1971. The values were calculated using an empirical formula by Slichter, described by Pazdro (1977). This formula is similar to Hazen's equation, but is applicable to the less uniform soils found in the reservoir area. The formula also makes a compensation for porosity.

Values of K determined according to Slichter are shown in Table 2, together with the formula. The hydraulic conductivities range from 2×10^{-5} to 1×10^{-10} m/s, for gravels and clays, respectively. These values are 1 to 2 orders of magnitude less than the results from the constant head tests. This is probably due to a greater fines content in deposits at depth. The surface material, in which the auger holes were drilled, has possibly had a portion of the fines washed out by surface runoff.

TABLE #1. HYDRAULIC CONDUCTIVITIES FROM FIELD TESTING

HAND-AUGERED HOLE	SAMPLE DESCRIPTION	Q (m^3/s)	L (m)	K (m/s)
1	SILT, some fine sand, trace clay	1.1×10^{-5}	0.85	2×10^{-5}
2	SILT, some fine sand, trace clay	1.3×10^{-5}	0.90	1×10^{-5}
3	FINE SAND, some silt, little clay	1.1×10^{-5}	0.85	9×10^{-6}
4	MEDIUM SAND, trace silt	1.5×10^{-5}	0.85	1×10^{-5}
5	SILT, some fine sand, trace clay	2.0×10^{-5}	0.85	2×10^{-5}
6	SILT, some fine sand, trace clay	2.0×10^{-5}	0.85	2×10^{-5}
7	MEDIUM SAND, trace silt and clay	2.3×10^{-5}	0.85	2×10^{-5}
8	MEDIUM SAND, trace silt, little clay	1.3×10^{-5}	0.90	9×10^{-6}
9	SILT, some fine sand, trace clay	1.5×10^{-5}	0.90	1×10^{-5}
10	FINE SAND, and silt and clay	6.6×10^{-6}	0.90	5×10^{-6}
11	SILT, some fine sand and clay	1.1×10^{-5}	0.90	8×10^{-6}
12	SILT, some fine sand and clay	1.1×10^{-5}	0.90	8×10^{-6}
13	SILT, some fine sand and clay	1.0×10^{-5}	0.90	8×10^{-6}
14	FINE SAND, and silt, trace clay	1.3×10^{-5}	0.90	1×10^{-5}
15	FINE SAND, and silt, little clay	9.9×10^{-6}	0.90	7×10^{-6}
16	SILT, and fine sand, trace clay	1.1×10^{-5}	0.54	2×10^{-5} (approx.)

TABLE #1. (Con't.)

HYDRAULIC CONDUCTIVITIES FROM FIELD TESTING

$$K = \frac{0.423}{86{,}400\ h^2} \log \frac{4h}{d}$$

$$12.5 < \frac{h}{r} < 50$$

Where: Q = flow rate of water added to maintain constant head (m^3/s)

h = height of head of water in hole (m)

d = diameter of hole (m)

K = hydraulic conductivity (m/s)

TABLE #2. HYDRAULIC CONDUCTIVITIES FROM GRAIN SIZE DISTRIBUTIONS

SAMPLE TYPE	POROSITY (n)	m	d_{10}^2 (mm)	K (m/s)
Alluvial Gravel	0.26	0.01187	0.73	2×10^{-5}
Alluvial Sand	0.42	0.05789	< 0.074	$< 8 \times 10^{-7}$
Interglacial Alluvial Clay	0.44	0.06776	< 0.001	$< 1 \times 10^{-10}$
Bedrock Sandstone	< 0.42	0.05789	< 0.074	$< 8 \times 10^{-7}$
Bedrock Shale	< 0.44	0.06776	< 0.001	$< 1 \times 10^{-10}$

$$K = 88.3\, d_{10}^2 \frac{m}{n}$$

Where: n = porosity (from Todd, 1959)
m = factor dependent on porisity (from Pazdro, 1977)
d_{10} = effective grain size (10% finer than by weight)
K = hydraulic conductivity

n	m	n	m
0,26	0,01187	0,32	0,02356
0,27	0,01350	0,33	0,02601
0,28	0,01517	0,34	0,02878
0,29	0,01694	0,35	0,03163
0,30	0,01905	0,36	0,03473
0,31	0,02122		

n	m	n	m
0,37	0,03808	0,43	0,06267
0,38	0,04154	0,44	0,06776
0,39	0,04254	0,45	0,07295
0,40	0,04922	0,46	0,07838
0,41	0,05339	0,47	0,08433
0,42	0,05789		

Hydraulic conductivities for bedrock sandstone and shale were approximated using grain size distributions from PFRA (1971) and are 8×10^{-7} and 1×10^{-10} m/s, respectively. These are relatively low conductivities. However, fracture permeability is not considered in this approach. Fracture flow would likely not be a problem in the bentonitic shales of the Willow Creek formation but is a possibility in the sandstones. Hydraulic conductivities calculated using the Slichter formula are approximate and serve only as a guide. Field tests should be made to verify the results.

5. CONCLUSIONS

5.1 The valley bottom is covered with 5-10 m of post-glacial alluvial fine- grained sands, silts, and clays. Pre-glacial sands and gravels of the Tee Pee Valley may be buried underneath this alluvium. The uplands are covered with some 20 m or less of till and glaciofluvial or glaciolacustrine deposits, ranging from gravel to clay-size material. Underlying the glacial till on the west side of the proposed reservoir, near the dam, is 6 m of interglacial (or pre-glacial) alluvium, consisting of clay with interbeds of clayey sand. Bedrock consists of interbedded sandstone and shale, and occasionally outcrops on the valley sites. Frequently, it is covered by less than 2 or 3 m of colluvium.

5.2 Hydraulic conductivities (K) were determined in the field for near surface sands and/or silts in the valley bottom and on the uplands, corresponding to alluvium and water-modified glacial deposits, respectively. The values, ranging from 2×10^{-5} to 5×10^{-6} m/s, are a moderate to high magnitude. Hydraulic conductivities were also calculated using grain size distributions of various soils and are 2×10^{-5} to 8×10^{-7} m/s for alluvial sands and gravels, and 1×10^{-10} m/s for the interglacial alluvial clay. These values are 1-2 orders of magnitude less than those determined from the field testing. No hydraulic conductivities were determined for the glacial till.

5.3 Hydraulic conductivities for the bedrock sandstone and shale were approximated, using grain size distributions and were 8×10^{-7} and 1×10^{-10} m/s, respectively. These hydraulic conductivities are relatively low and, as such, are in general agreement with previous limited drilling and testing in the bedrock. However

this approach does not consider fracture permeability which may be very important in rock masses.

5.4 No major hydrogeological problems with the proposed reservoir were identified during this preliminary study.

a) Flooding on the uplands does not appear to be a concern due to the high ground surface elevations of areas bordering the reservoir.

b) A rise in the groundwater surface adjacent to the reservoir would occur due to water impoundment, but would likely have little effect upon domestic wells as most wells are completed in bedrock.

c) The groundwater chemistry in areas adjacent to the reservoir would be altered by the introduction of reservoir water and by the cyclic aeration and saturation of soil and/or bedrock due to the reservoir lowering and raising. However, the reservoir water would be of better chemical quality than the existing groundwater and would likely have a beneficial impact on groundwater quality in aquifers in the area. Cyclic aeration and saturation, due to fluctuations in the reservoir level, would be limited to areas adjacent to the reservoir. Since most domestic wells are completed deeper in bedrock, any adverse affects would be minimal.

d) There is not enough data at present to determine groundwater seepage losses through the valley walls and bottom. The groundwater regime, geological units and hydraulic conductivities of these units need to be better defined in the reservoir

area before such losses can be estimated. However, an indication of water seepage is give by the regional geology. Glacial till, which surrounds the reservoir, is typically a low hydraulic conductivity material. The inter-glacial alluvial clay, which underlies this till on the west side of the reservoir, appears to have a low K, while the post-glacial alluvium in the reservoir bottom appears to have a moderate to high K. Thus, any water losses would likely be primarily through the valley bottom.

5.5 This study does not consider slope stability concerns, possible effects of the proposed reservoir on an earthfill dam, or seepage through the dam foundations and abutments.

6. RECOMMENDATIONS FOR A QUANTITATIVE ASSESSMENT OF THE RESERVOIR

1. The depth to bedrock and the groundwater surface should be accurately delineated around and in the reservoir area. As well, the extent of the Tee Pee Valley sands and gravels, and the sand lenses in the interglacial alluvium on the west side of the reservoir, should be determined.

2. It is recommended that piezometer nests be installed around the reservoir perimeter and in the valley bottom to define the local groundwater regime. At least two piezometers should be installed at each site, one in bedrock and one in the surficial deposits. The piezometers can also be used for hydraulic conductivity tests and water sampling.

3. In-situ hydraulic conductivity tests should be performed on all geologic units at the site, e.g. bedrock, preglacial sand and gravels, interglacial alluvium, glacial till, and post-glacial alluvium.

4. If thick (for example, greater than 3 m) pre-glacial sands and gravels are encountered in the river valley, an aquifer test should be conducted to determine aquifer parameters. These would be required for the design of a dewatering system for foundation excavation. If a lesser thickness is encountered, consideration should be given to the excavation of these sands and gravels (under the dam) and infilling with impervious material.

5. The quality of water in wells close to the reservoir should be monitored, both before and after impoundment, to accurately define the groundwater chemistry. Although any changes in the chemistry are likely to be beneficial, such monitoring will help prevent unnecessary litigation against Alberta Environment.

Respectfully, submitted:

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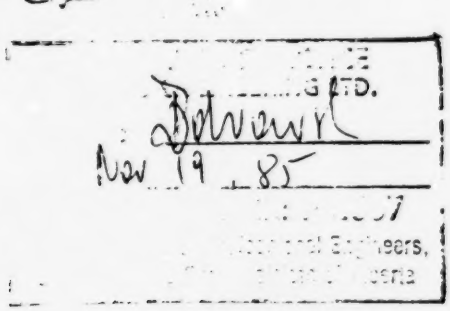
Dr. T. L. Dabrowski, P. Eng.



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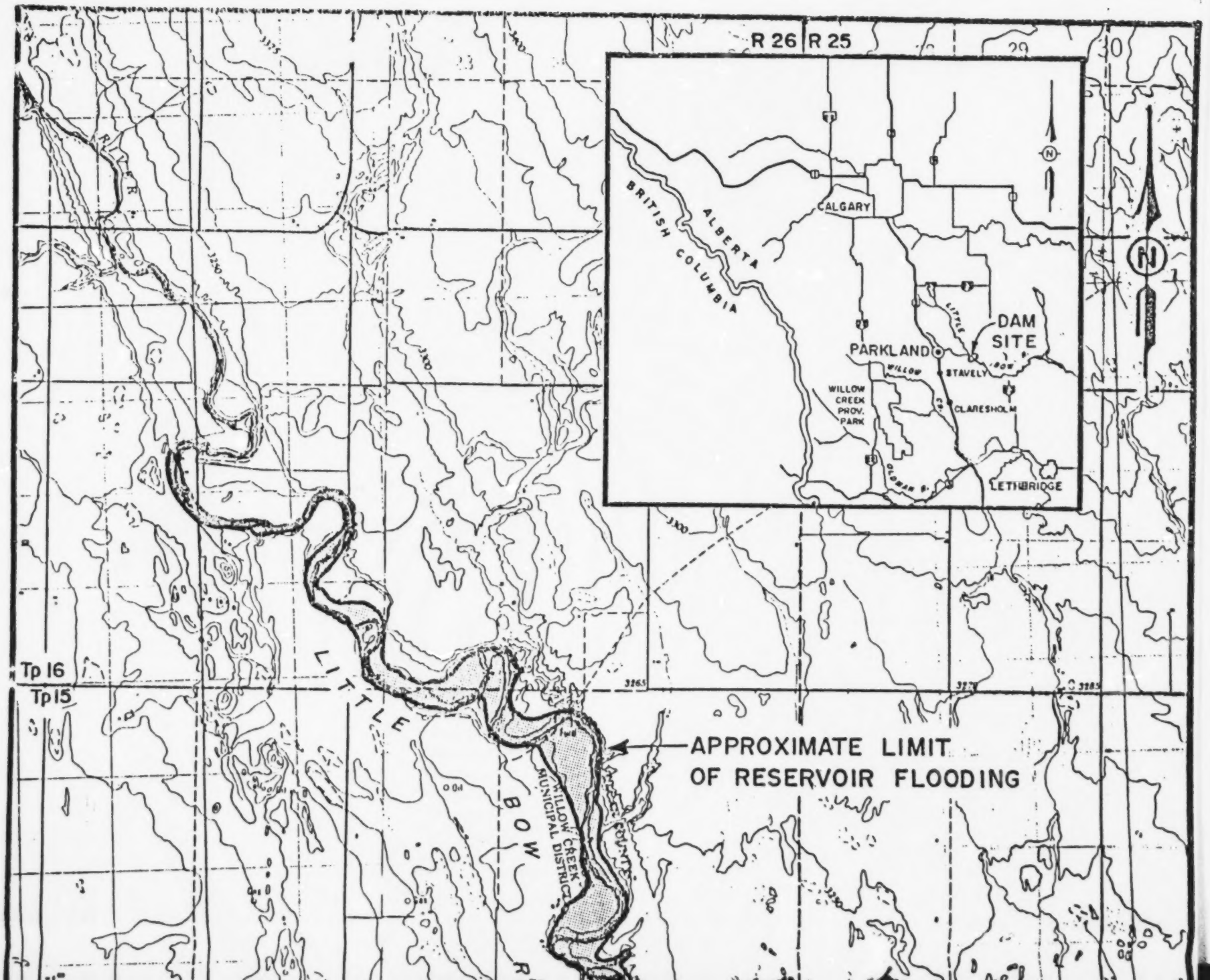
R 26
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CALGARY
ALBERTA
BRITISH COLUMBIA
PARKLAND
DAM SITE
STAVELY
WILLOW CREEK PROV. PARK
CLARESHOLM
LETHBRIDGE
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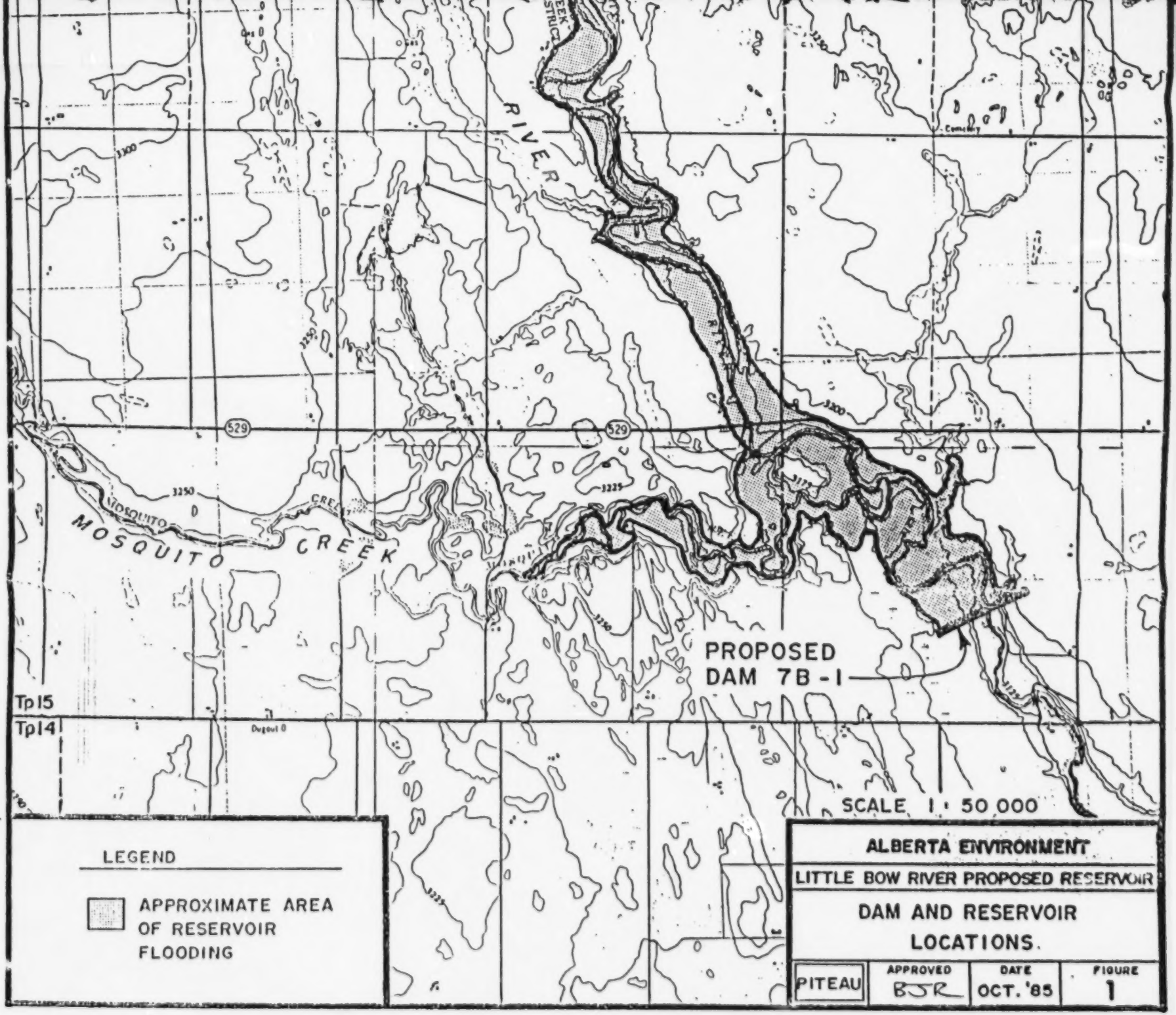
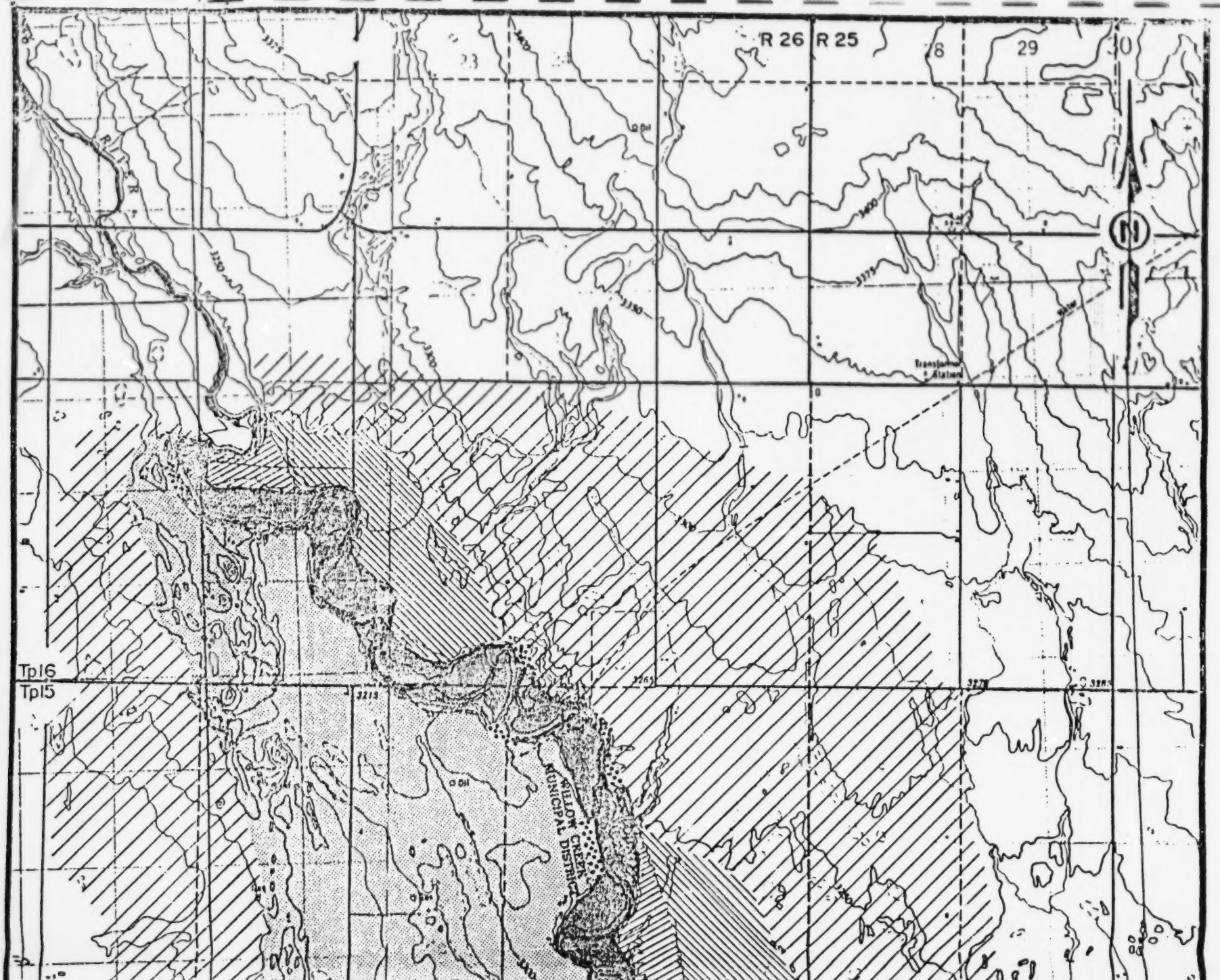
Tp 15
LITTLE BOW R.
APPROXIMATE LIMIT OF RESERVOIR FLOODING
WILLOW CREEK MUNICIPAL DISTRICT
FOOTHILLS COUNTY


RIVER
529
529
MOSQUITO CREEK
PROPOSED
DAM 7B-1
Tp15
Tp14
SCALE 1 : 50 000
LEGEND
APPROXIMATE AREA
OF RESERVOIR
FLOODING
ALBERTA ENVIRONMENT
LITTLE BOW RIVER PROPOSED RESERVOIR
DAM AND RESERVOIR
LOCATIONS.
PITEAU
APPROVED
BJR
DATE
OCT. '85
FIGURE
1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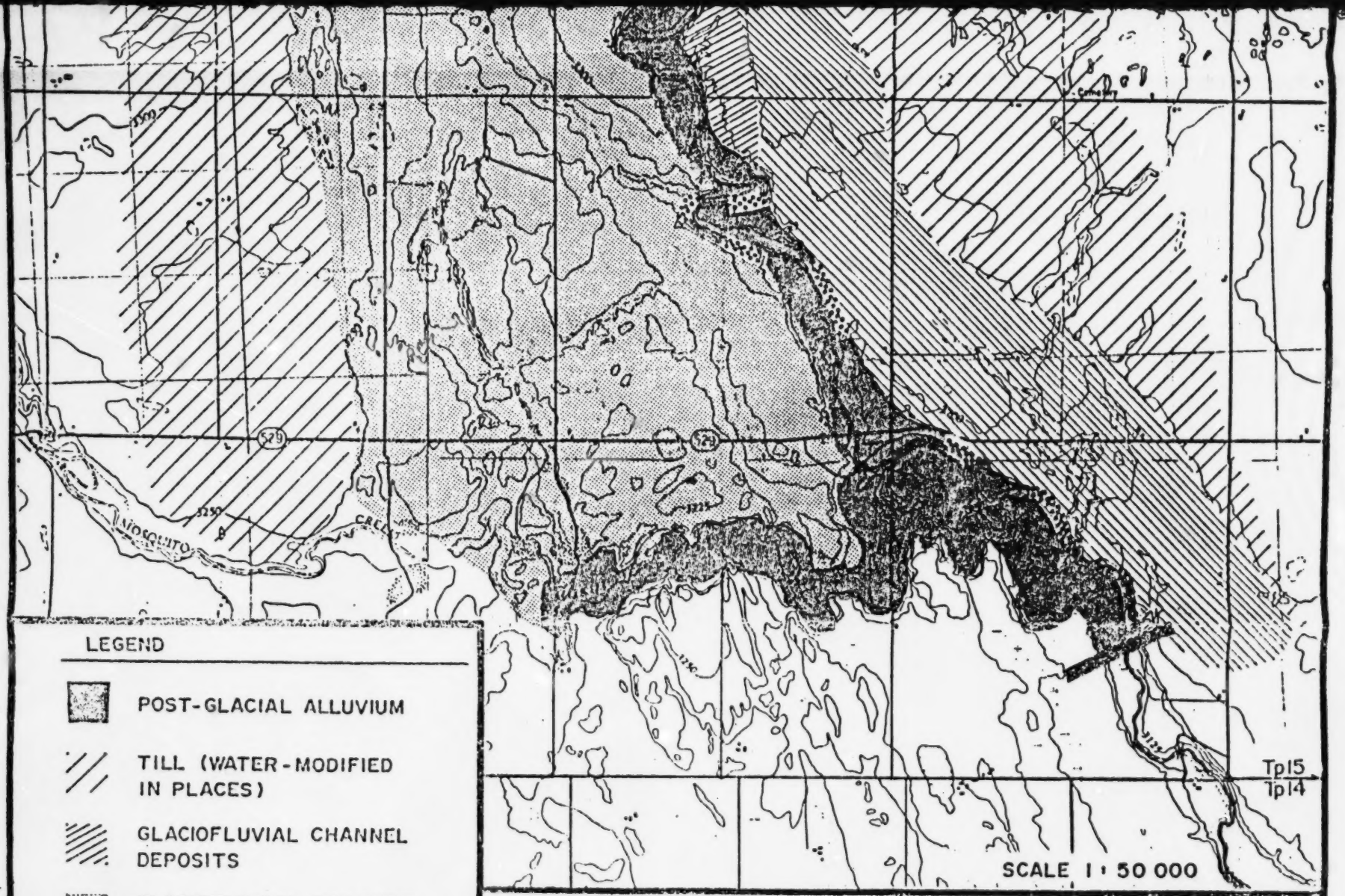
MUNICIPAL DISTRICT



NOTES

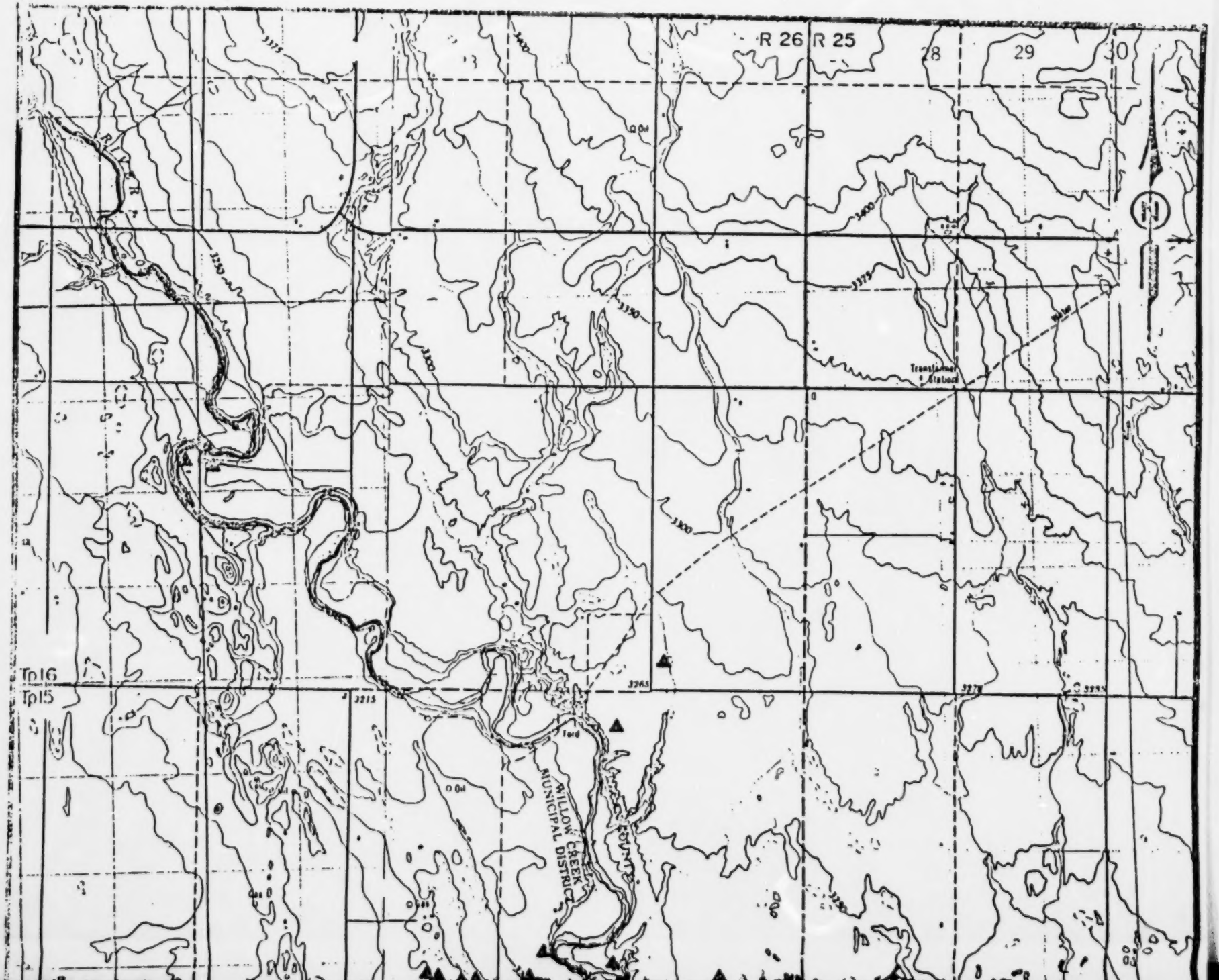
1. Geology after A. MacS.Stalker (1957) (modified)
2. Surficial geology is subject to interpretation. Actual conditions may vary from that shown.

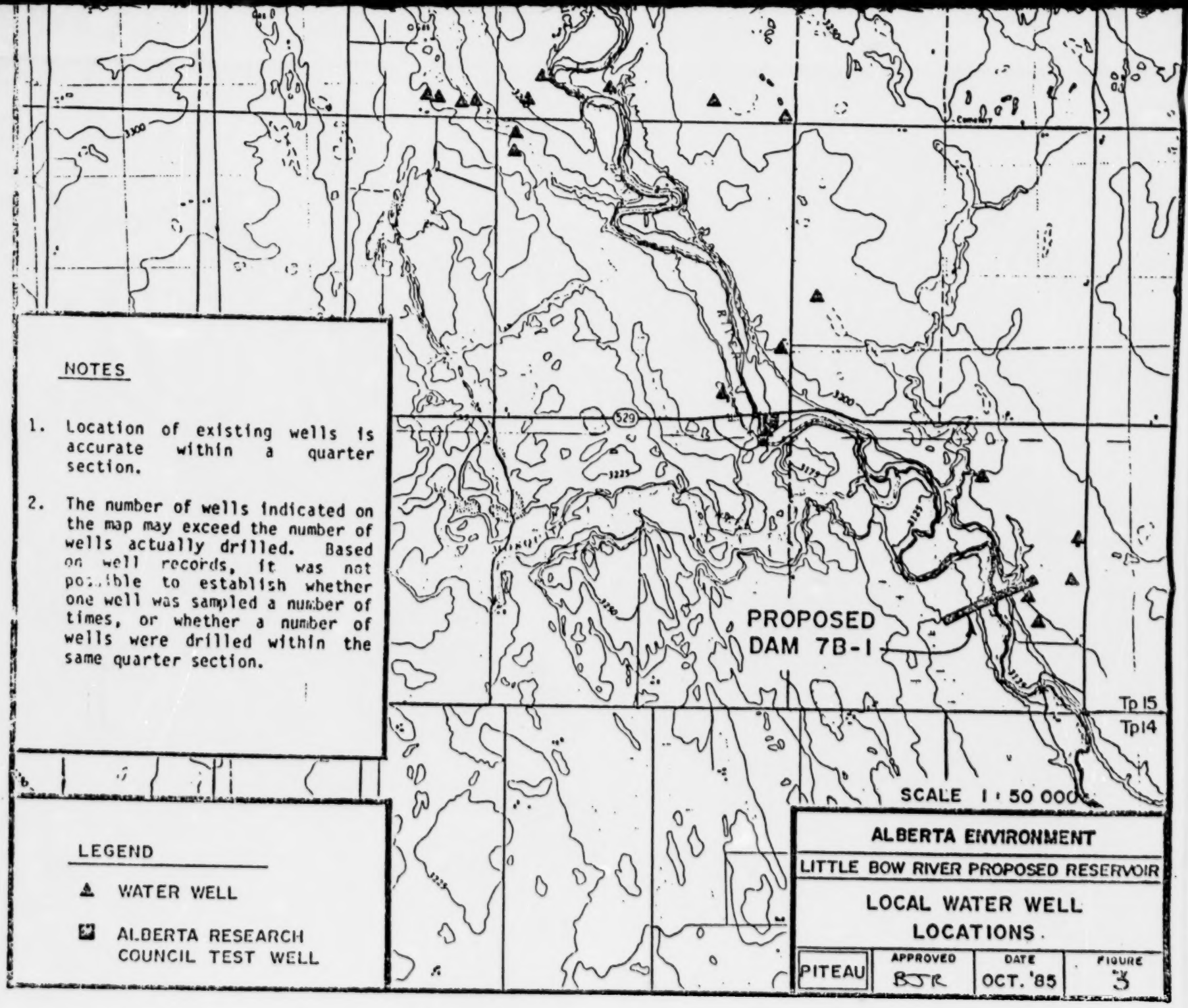
ALBERTA ENVIRONMENT

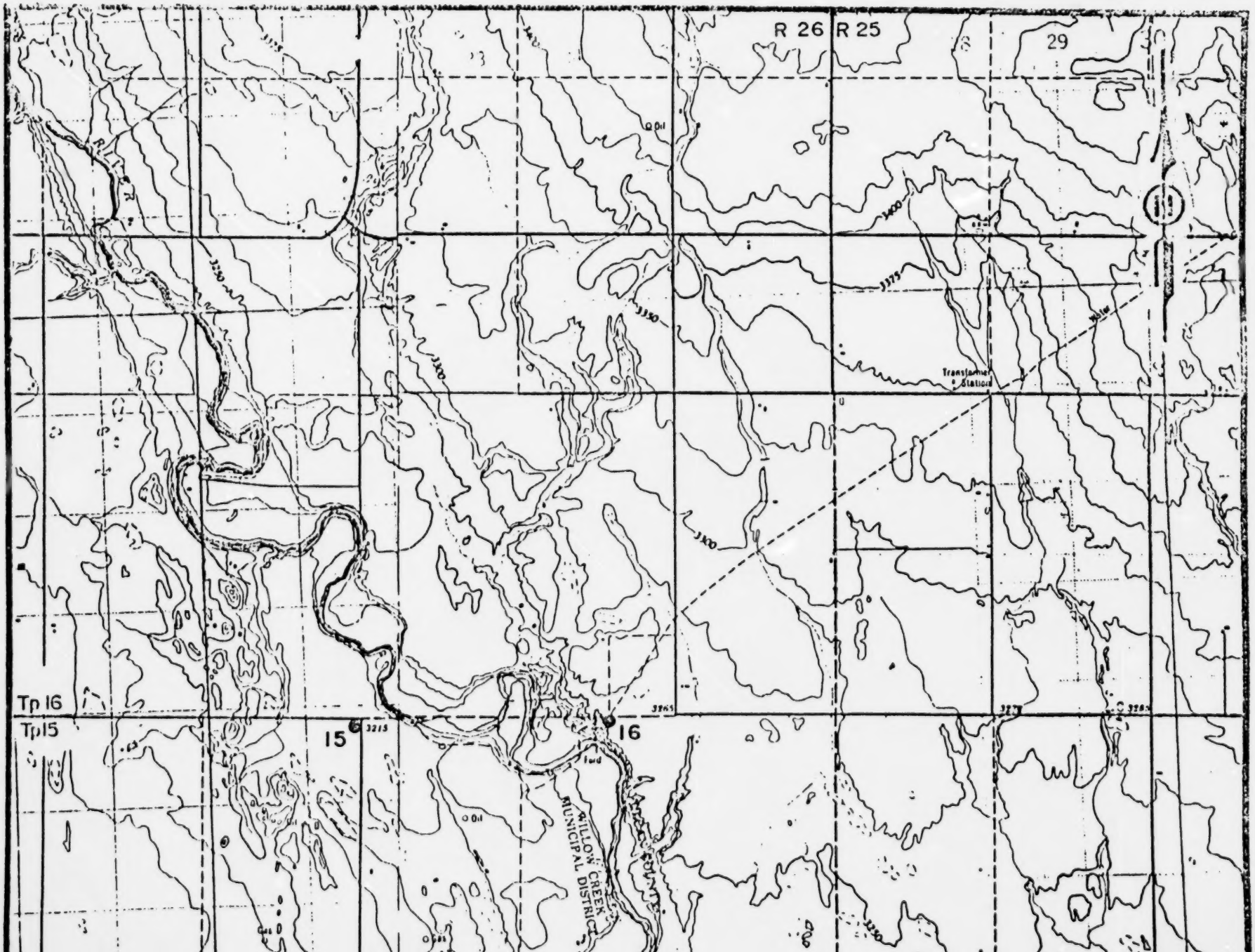
LITTLE BOW RIVER PROPOSED RESERVOIR

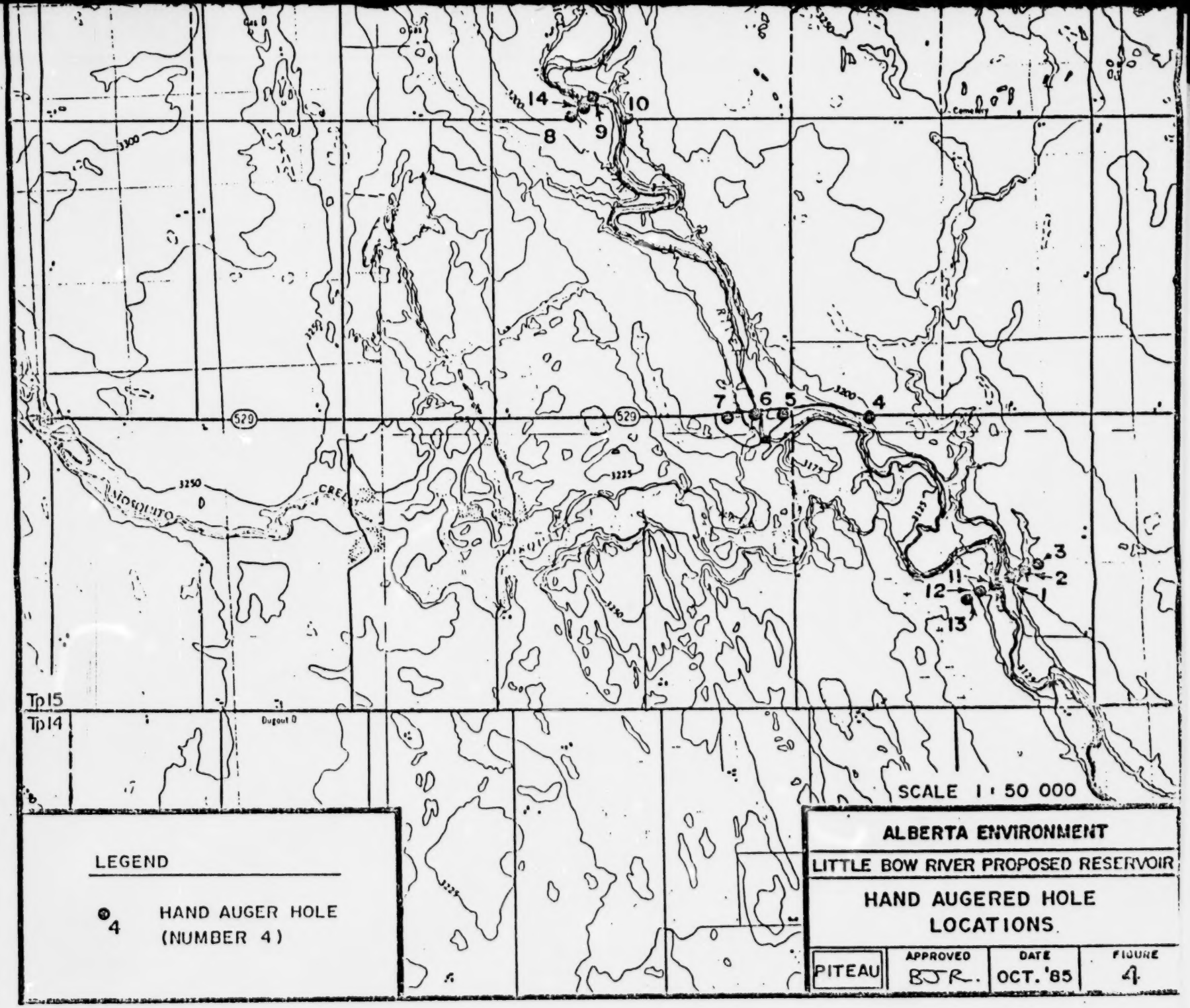
SURFICIAL GEOLOGY IN THE RESERVOIR AREA

PITEAU	APPROVED	DATE	FIGURE
	BJR	OCT. '85	2

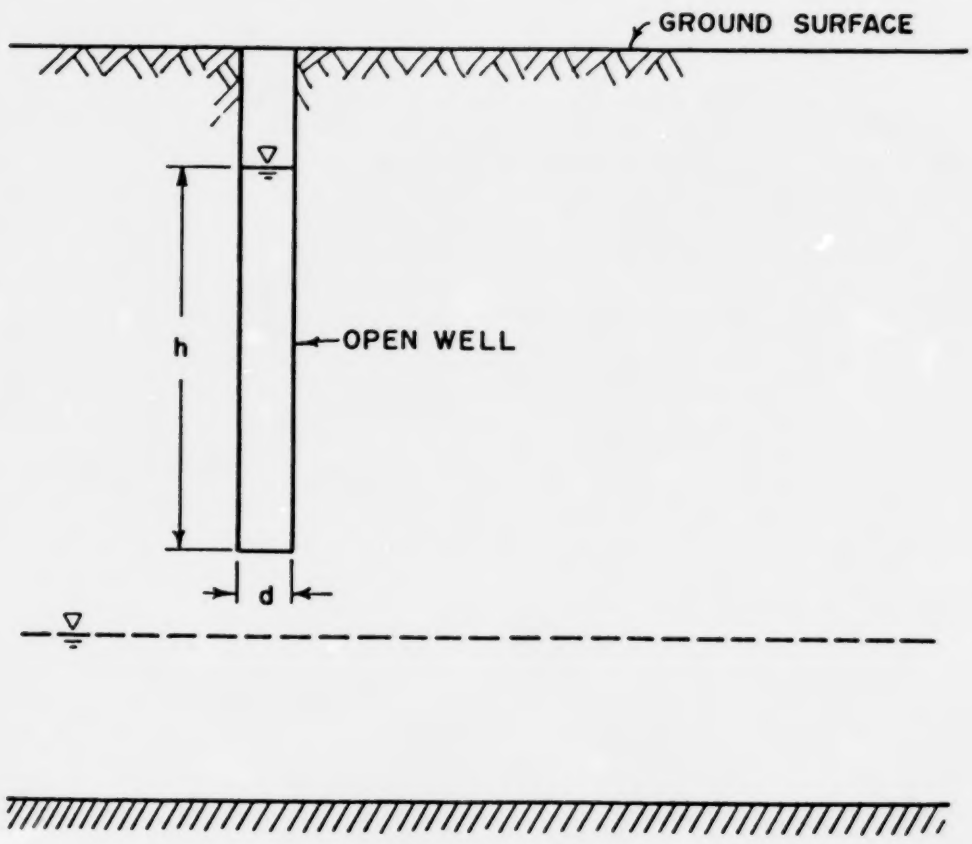

R 26
R 25
28
29
30
Tp16
Tp15
WILLOW CREEK MUNICIPAL DISTRICT
Transformer Station


NOTES
1. Location of existing wells is accurate within a quarter section.
2. The number of wells indicated on the map may exceed the number of wells actually drilled. Based on well records, it was not possible to establish whether one well was sampled a number of times, or whether a number of wells were drilled within the same quarter section.
LEGEND
WATER WELL
ALBERTA RESEARCH COUNCIL TEST WELL
PROPOSED DAM 7B-1
529
Tp 15
Tp14
SCALE 1 : 50 000
ALBERTA ENVIRONMENT
LITTLE BOW RIVER PROPOSED RESERVOIR
LOCAL WATER WELL LOCATIONS.
PITEAU
APPROVED BJR
DATE OCT. '85
FIGURE 3


R 26
R 25
29
Tp 16
Tp 15
15
16
Transformer Station
WILLOW CREEK MUNICIPAL DISTRICT
3400
3375
3350
3325
3300


14
10
8
9
7
6
5
4
529
529
3250
3225
3200
3175
3150
3125
3100
3300
RIVER
MOSQUITO
CREEK
3
2
1
11
12
13
Tp15
Tp14
Dugout D
SCALE 1 : 50 000
LEGEND
HAND AUGER HOLE (NUMBER 4)
ALBERTA ENVIRONMENT
LITTLE BOW RIVER PROPOSED RESERVOIR
HAND AUGERED HOLE LOCATIONS
PITEAU
APPROVED
BJR.
DATE
OCT. '85
FIGURE
4

JOB NO. A85 2106



(EMPIRICAL FORMULA)

$$K = \frac{0.423Q}{86{,}400\ h^2} \log\left(\frac{4h}{d}\right) \quad \text{for} \quad 12.5 < \frac{h}{r} < 50$$

ALBERTA ENVIRONMENT LITTLE BOW RIVER PROPOSED RESERVOIR	PITEAU & ASSOCIATES GEOTECHNICAL CONSULTANTS VANCOUVER CALGARY	
HYDRAULIC CONDUCTIVITY TEST IN OPEN WELL ABOVE THE GROUNDWATER SURFACE	BY: IAL BOR	DATE: OCT. 85 FIGURE: 5

APPENDIX II

BOREHOLE LOGS

BOREHOLE LOGS

Hand-Augered Hole #1

0.0 - 0.1 m	Topsoil.
0.1 - 1.0 m	SILT, some fine sand, trace clay, light brown, damp.

Hand-Augered Hole #2

0.0 - 0.05 m	Topsoil.
0.05 - 1.0 m	SILT, some fine sand, trace clay, light brown, damp, medium dense.

Hand-Augered Hole #3

0.0 - 0.06 m	Topsoil.
0.06 - 0.9 m	FINE SAND, some silt, little clay, light brown, damp, medium dense (occasional gravel and cobbles).

Hand-Augered Hole #4

0.0 - 0.9 m	MEDIUM SAND, trace silt, light brown, moist, medium dense (some rounded gravel).

Hand-Augered Hole #5

0.0 - 0.06 m	Topsoil.
0.06 - 1.0 m	SILT, some fine sand, trace clay, light brown, damp, medium dense.

Hand-Augered Hole #6

0.0 - 0.05 m	Topsoil.
0.05 - 1.0 m	SILT, some fine sand, trace clay, light brown, moist, medium dense.

Hand-Augered Hole #7

0.0 - 0.04 m	Topsoil.
0.04 - 1.0 m	MEDIUM SAND, trace silt and clay, light brown, dry, medium dense (some sub-rounded gravel).

Hand-Augered Hole #8

0.0 - 0.07 m	Topsoil.
0.07 - 1.0 m	MEDIUM SAND, trace silt, little clay, light brown, dry, medium dense (some rounded gravel).

BOREHOLE LOGS (Cont'd)

Hand-Augered Hole #9

0.0 - 0.08 m	Topsoil.
0.08 - 1.0 m	SILT, some fine sand, trace clay, light brown, moist-wet, medium dense.

Hand-Augered Hole #10

0.0 - 0.08 m	Topsoil.
0.08 - 1.0 m	FINE SAND, and silt and clay, light brown, damp, medium dense (occasional sub-rounded gravel)

Hand-Augered Hole #11

0.0 - 0.05 m	Topsoil.
0.05 - 1.0 m	SILT, some fine sand and clay, light brown, moist, medium dense.

Hand-Augered Hole #12

0.0 - 0.06 m	Topsoil.
0.06 - 1.0 m	SILT, some fine sand and clay, light brown, damp, loose.

Hand-Augered Hole #13

0.0 - 0.05 m	Topsoil.
0.05 - 1.0 m	SILT, some fine sand and clay, light brown, damp, medium dense (occasional well-rounded gravel).

Hand-Augered Hole #14

0.0 - 0.05 m	Topsoil.
0.05 - 1.0 m	FINE SAND, and silt, trace clay, light brown, moist, medium dense (occasional sub-rounded gravel).

Hand-Augered Hole #15

0.0 - 0.1 m	Topsoil.
0.1 - 1.0 m	FINE SAND, and silt, little clay, light brown, damp, medium dense.

Hand-Augered Hole #16

0.0 - 0.04 m	Topsoil.
0.04 - 0.6 m	SILT, and fine sand, trace clay, light brown, moist, medium dense (occasional rounded gravel).